The Role of the Pre-Frontal Cortex in Step Initiation and Aging Related Changes

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Statement of Sources

I declare that this report is my own original work and that contributions of others have been duly acknowledged.

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List of Abbreviations

APA: Anticipatory Postural Adjustment

BDR: Backwards Digit Recall

CoP: Centre of Pressure

CRUNCH: Compensation-Related Utilization of Neural Circuits Hypothesis

CS: Choice Step

DLPFC: Dorsolateral Pre-Frontal Cortex

DT: Dual Task

DTC: Dual Task Cost

EF: Executive Functions

FDR: Forwards Digit Recall

fNIRS: functional Near Infrared Spectroscopy

FP1: Force Plate 1

FP2: Force Plate 2

HbO_2: Oxyhaemoglobin

HHb: De-oxyhaemoglobin

PFC: Pre-Frontal Cortex

RT: Reaction Time

SD: Standard Deviation

SS: Simple Stepping

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9876 Words

Abstract

Fast voluntary stepping is crucial to reducing fall risk in older adults. Older and younger adults (n = 20, m_{age} = 69.4 years; n =21, m_{age} = 26.9 years respectively) performed stepping tasks on force plates while functional Near Infrared Spectroscopy recorded neural activity in the Pre-Frontal Cortex (PFC). It was hypothesised that the PFC plays a role in step initiation and therefore would have greater activity for a choice step compared to a simple step, and this was supported (p = .041, ηp^2 = .11). Age differences in stepping under levels of cognitive load (forwards and backwards digit recall dual tasks) and step complexity (simple and choice stepping) were also investigated. Older adults' step initiation was significantly more slowed by the increased step complexity (p = .022, r = .44). For the backwards digit recall dual task, older adults employed a slower stepping strategy for both step types (p = .007, r = .43). Conversely, young adults maintained fast step initiation for both step types and upregulated PFC activity more for the choice step (p = .003, r = .47). Together these findings suggest that older adults could maintain comparable stepping and PFC involvement up until executive functions were strained through either increased step decision making or higher cognitive load. Future research aiming to improve older adults' stepping speed to reduce fall risk should target more complex stepping conditions.

Falling in the elderly is a large societal concern due to the distressing consequences and costs to health care systems (Yoshida-Intern, 2007). Poorer cognitive functioning (Mirelman et al., 2012) and being slower to take a voluntary step are implicated in fall risk (McLlroy & Maki, 1996). Crucially, although it was previously thought that gait was an automatic process relying on subcortical brain structures (Hausdorff, Yogev, Springer, Simon, & Giladi, 2005) recent studies suggest that the initial phase of gait is under higher cortical control (Huppert, Schmidt, Beluk, Furman, & Sparto, 2013). While age related changes in the brain are well documented (Buckner, 2004), how the *function* of the Pre-Frontal Cortex (PFC) changes with age to influence step preparation and stepping speed is not well understood. This is largely because traditional neuroimaging techniques cannot measure cortical activity *during* balance and stepping activities.

The Role of Step Initiation in Falls

The incorrect transfer of bodyweight such as leaning too far from the base of support in walking or standing accounts for 41 % of falls (Robinovitch et al., 2013). In one large study that captured falls in the elderly, 24 % of these weight shift errors occurred in forward walking, 13 % while stationary and 11 % on step initiation (Robinovitch et al., 2013).

Step initiation refers to the period between standing and the swinging foot touching the ground to complete the first step. To be able to maintain lateral stability while the body is propelled forwards, Anticipatory Postural Adjustments (APAs) must first be made. The person’s centre of mass is initially shifted laterally towards the foot that will be lifted (swing foot), in order to propel their centre of mass over the stance foot. This preparatory motion ensures the body will not topple toward the side of the swing foot when it is lifted off the ground (Honeine, Schieppati,

Crisafulli, & Do, 2016). The weight-shifts associated with the APA can be precisely detected on a force plate, a platform that measures centre of pressure reactions. The latency of the APA provides information about the decision time to initiate a step, whereas time from foot off to foot on represents information on the motoric aspect of the step (St George, Fitzpatrick, Rogers, & Lord, 2007). The lateral direction of the APA (left or right shift) is an early indication of which foot has been chosen to take the step. If an APA is initiated, but the person decides to switch stepping feet (due to visual feedback of changing environmental conditions) weight must be shifted to the correct side prior to foot lift off (Cohen, Nutt, & Horak, 2011). This lengthens latency to step which increases fall risk (Lord & Fitzpatrick, 2001).

Executive Function, the Pre-Frontal Cortex, and Falls

Executive Function (EF) is an umbrella term for up to 30 diverse cognitive processes that are mediated by the PFC, specifically the Dorsolateral PFC (DLPFC) and the Anterior Cingulate Cortex (ACC) (Goldstein & Naglieri, 2014). Lezak, Howieson, Bigler, and Tranel (2012) conceptualise EFs as having four components; planning, volition, purposeful action and effective performance. It has also been described as a directive system that controls neuropsychological functions such as memory, motor skills, language, and visuospatial functions (Gioia & Isquith, 2004). However, in the literature, it is more often defined by the processes required to carry out these actions such as attention, and inhibition (Suchy, 2009).

EFs are vulnerable to lesions, a loss of dendritic branching (Burle, Hasbroucq, Tandonnet, & Vidal, 2004) and to grey matter loss – accordingly, EFs have been found to decline in older age (Buckner, 2004). Crucially, poor EF is associated with poorer balance (Kearney, Harwood, Gladman, Lincoln, & Masud, 2013), so much so that those with low executive functioning are three times more

prone to falls (Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010). However, most of the processes describing which EFs are important to gait are only theorised (Yogev, Hausdorff, & Giladi, 2008).

One of the more well defined links between EF and age based differences in gait is the role of attention (the ability to select relevant stimuli and responses out of irrelevant stimuli and responses) (Wong, Haith, & Krakauer, 2015). Because attention is a limited capacity system, when performing two activities at once that require the same cognitive resources, performance on one or other will drop (Woollacott & Shumway-Cook, 2002). Dual tasking paradigms therefore provide both a way to manipulate attentional demands and an easily observable measure - a decline in performance. For this reason, a considerable volume of research has focused on dual tasking in gait to understand how executive functioning may be linked to falls and declines in postural control.

Challenging EF and Reduced Gait Performance in Older Age

A review by Al-Yahyaa et al. (2011) found that older adults had slower and more variable gait when dual tasking compared to younger adults. However, the results varied drastically depending on the nature of the secondary task used. Many studies that use cognitive distractors such as walking and talking reveal no effect or have inconsistent results. So much so that Walshe, Patterson, Commins, and Roche (2015) argue that the underuse of tasks involving higher level EFs has created ambiguity in findings and limited clinical contribution.

Increasing the demands placed on EFs by imposing decision making on the gait task (such as manipulating where, when, or how to step) offers more consistent findings. Step preparation often occurs in unpredictable environments such as navigating foot placement around a pet or deciding where the safest place to step is.

Decision making in step initiation therefore holds ecological value to understanding falls in the elderly. However very few studies have investigated this.

Of the few studies that have incorporated decision making into stepping reaction time paradigms, age decline in performance with increased step complexity can be seen. Cohen et al. (2011) found that with increased decision-making requirements of a step, the effect on APA latency was three times greater for older than for younger adults. Sparto et al. (2013) found that APA latencies were progressively longer in older adults as the task complexity increased from a simple step, to a choice step, and longer again in tasks where added decisions needed to be made. Combining both a step decision element and a visuospatial memory task, St George et al. (2007) found that dual tasking significantly increased APA latency in older adults.

Finally, Coppin et al. (2006) found that scores on the Trail Making Test (a measure of EF) were unrelated to performance on low complexity gait tasks. Conversely, scores were related to more complex gait such as object navigation and picking up objects. Moreover, Coppin et al. found there was a greater deficit when needing to monitor the environment when also under increased cognitive task load.

In sum, the above studies highlight that loading EF by either dividing attention (dual tasks) or increasing the decision requirements of the motor task (choice step), or both, will degrade older adults' performance more than young adults.

Age differences in PFC Activation and Performance When Under Cognitive Load

Theories of aging are well placed to explain the performance costs seen in the elderly in dual task studies. Moreover, they are well placed to predict corresponding

PFC activation. It has been widely shown that the elderly have differences in PFC activity in cognitive tasks without a motor component (Grady, 2008). Some have found lower PFC activity in the elderly compared to young adults, known as under recruitment (Logan, Snyder, Sanders, Morris, & Buckner, 2002; Schroeter, Zysset, Kruggel, & Yves von Cramon, 2003). Surprisingly, the most consistent finding is in fact increased PFC activity in older adults compared to young adults (Grady, 2008). The nature of this overactivation and its impact on performance is controversial. Over recruitment of the PFC can be related to improved performance (Cabeza, Anderson, Locantore, & McIntosh, 2002) indicating that the extra recruitment is compensatory. Conversely, it occasionally can be unrelated to task performance, instead interpreted as reflecting neural inefficiency (Logan et al., 2002).

The Compensation-Related Utilization of Neural Circuits Hypothesis (CRUNCH)

The dominant neurocognitive aging theory, the CRUNCH (Reuter-Lorenz & Cappell, 2008), offers an explanation for the variable age-related cortical activation levels. Proponents of the CRUNCH discuss that differences in performance costs and activation levels observed will depend on task difficulty. Specifically, in older age, greater cortical activations are required for easier tasks. Without this increased activation, performance would be poorer. As task complexity increases, in older adults, activations will plateau (or even decrease), and performance will fall. Whereas activation in a younger population continues to increase, and performance on the task is not as negatively impacted. According to the CRUNCH, in easier tasks, older adults recruit areas that would normally only be active in young adults at higher levels of difficulty. The older adults are required to recruit reserve resources

for simpler tasks for comparable performance (Stern, 2009) due to grey and white matter loss in the PFC (Buckner, 2004).

Functional Near Infrared Spectroscopy; a Way to Measure Cortical Activity During Gait

The development of functional Near-Infrared Spectroscopy (fNIRS) has enabled cortical activity during balance and locomotor activities to be measured in a way not possible with traditional neuroimaging techniques (Strangman, Boas, & Suttona, 2002). FNIRS is a non-invasive imaging technique that emits near-infrared light (using optic cables under a cap) into the brain from a source to a detector. The distance between the source and the detectors dictates the depth of cortical tissue that can be assessed. As the separations increase, the light path can extend deeper into the brain (Scholkmann & Wolf, 2012).

FNIRS works on the principle that increased neural activity causes increased oxygen consumption and increased blood flow (Scholkmann & Wolf, 2012). Most biological tissue such as skin and bone are transparent to near-infrared light, while oxyhaemoglobin (HbO_2) and de-oxy-haemoglobin (HHb) molecules in the blood are absorbers in the 700-900nm spectrum (Severinghaus, 2007). Light absorption is measured and converted into HHb and HbO_2 levels using the Modified Beer Lambert Law (Delpy et al., 1988). This provides a measure of cortical oxygen consumption. Changes in Oxygenated Haemoglobin (ΔHbO_2) have been found to be the most sensitive measure of cerebral activation (Hoshi, Kobayashi, & Tamura, 2001).

FNIRS measurements have been found to be highly correlated with functional Magnetic Resonance Imaging in both cognitive (Cui, Bray, Bryant, Glover, & Reiss, 2011) and motor tasks (Steinbrinka et al., 2006). Moreover, fNIRS is sensitive to cognitive load; when a cognitive task is performed that has increasing

difficulty, fNIRS shows corresponding increases in cortical activity (Smith, Jonides, Marshuetz, & Koeppe, 1998). Further to this, fNRIS has been found to be effective at differentiating within divisions of the PFC (divergent validity). For example, Krampe et al. (2018) found that they could observe neural activity for decision making in the Dorsolateral PFC while the Ventromedial PFC did not increase activity.

Age Differences in Cortical Activity During Gait, in View of the CRUNCH

To date, almost all research on cognitive control of gait using fNIRS has been performed during steady state gait, not step initiation. This aside, prior fNIRS dual tasking studies of gait suffer from similar methodological issues as those previously discussed. Very few studies have used a design that incorporates multiple levels of secondary cognitive task complexity, or tasks that load EF through increased motor decisions. One such study of steady state gait on a treadmill had results similar to that predicted by the CRUNCH.

Beurskens, Helmich, Rein, and Bock (2014) found that older adults showed lower neural activity in a walking and visual perception dual task compared to a single task (walking alone), whereas the younger group showed the opposite effect. Furthermore, lower neural activity in the older group was associated with worse gait performance (step length and variability) in line with the CRUNCH. However, contrary to the CRUNCH, at lower levels of task demand no age differential activation was observed.

These results provide the neural correlates to the familiar theme painted so far; a lack of age differences observed for easier tasks, but a distinct age difference under higher task load. While other age-based literature using fNIRS is scarce, other available fNIRS literature (non-aged focused) provides valuable insight into the role that the PFC may play in step initiation.

FNIRS Findings Applicable to the Step Initiation Phase of Gait

Koenraadt, Roelofsen, Duysens, and Keijsers (2014) investigated PFC activation differences over specific time periods in walking tasks (pre cue, early phase and late phase). They ran trials of 35 seconds of treadmill walking and treadmill walking on predefined spots (precision stepping) and found that in both conditions the greatest PFC activity occurred in the phase prior to the cue. In addition, the more complex gait task (precision stepping) required greater PFC involvement.

Suzuki, Miyai, Ono, and Kubotab (2008) also found that the preparation of a step may be important to study. They compared trials of prepared walking (where a cue 'ready' was given), to normal walking trials (where no cue was given). The cue 'ready' increased PFC activity both prior to beginning walking and in the acceleration phase.

The Void in fNIRS Gait Literature – Why is There Increased PFC Activity Before a Step?

The above findings by Koenraadt et al. (2014) and Suzuki et al. (2008) taken together indicate that the PFC does play a role in step initiation. However, exactly what role the PFC plays is not well understood. Attention for when and where to step is a potential function. The neuropsychological literature divides attention into three facets; alerting, orienting, and executive attention (Fan, McCandliss, Sommer, Raz, & Posner, 2002). *Orienting* refers to selecting relevant information out of stimuli and is thought to be subserved by the parietal lobe and frontal eye fields (Raz & Buhle, 2006). *Alerting* refers to the ability to focus in preparation for incoming stimuli (Raz & Buhle, 2006). It can be defined as goal directed preparedness and is thought to be mediated by the Dorsolateral PFC and the ACC (Raz & Buhle, 2006). *Executive*

attention (also sometimes referred to as attentional control, select attention, effortful control and supervisory attention) is the attention needed to monitor conflict among responses and thoughts. It is mediated by the PFC circuits and is concerned with planning, inhibitory control and working memory (Raz, 2004). It is this 'attentional control' that is traditionally discussed in more complex gait tasks such as the precision task in the study by Koenraadt et al. (2014).

The field of motor control discuss cognitive control in movement from a different (although not necessarily exclusive) perspective. Not only is the deployment of attention seen as a pre-requisite for motor planning (Wong et al., 2015) but Wolpert and Landy (2012) describe that motor control *is* decision making. Furthering this concept of decision making, and crucial to step preparation, Cohen et al. (2011) posit that to select the correct limb for step preparation (step decision), inhibition of the incorrect stepping leg is required.

To date, the neural correlates of monitoring the environment to select the correct stepping foot (choice stepping) have not been investigated. While there is no fNIRS literature to date investigating whether a choice stepping task (step location unknown prior to the step cue) elicits greater PFC activity compared to simple step (step target in known location prior to step cue) other inhibition research supports that this would be the case. Using a choice response paradigm, Duque, Labruna, Verset, Olivier, and Ivry (2012) applied Transcranial Magnetic Stimulation (TMS) over the lateral PFC and found it reduced inhibition related to competition resolution (such as which finger to press). The lateral PFC was related to goal maintenance and selecting the appropriate response to the given context.

Regardless of which theoretical outlook is ascribed to (executive attention, alerting attention, motor preparation, or inhibition), based on past findings it is

conceivable that the PFC activity observed when initiating gait could be related to cognitive processes needed to make a step decision with the correct foot given the environment.

The Current Study

Aim 1: To Determine the Role of the Increased PFC Activity in Step Initiation

As the function of increased PFC activity during step initiation is unclear, the current study aimed to fill this void. To understand the role of the PFC in step initiation, the neurophysiological correlates of increasing decision making and response monitoring requirements in stepping were investigated. Specifically, pre-frontal cortical activation differences were investigated when comparing a simple step (step limb and step location were known prior to the cue to step) to a choice step (step limb and location were unknown until the cue to step). If the PFC is involved in decision making for step initiation (e.g. limb selection, attention, and response monitoring), then a greater increase in PFC activity would be expected in a step that required more monitoring and decisions to be made. Therefore, it was hypothesised that *there would be increased pre-frontal cortical activity in a choice step compared to a simple step.*

Aim 2: To Understand Age Related Changes in Step Initiation Under Task Load

As age differences in cognitive control of step preparation are poorly understood, and rarely studied using tasks that strain EFs, the current study aimed to fill this void. Based on the CRUNCH (Reuter-Lorenz & Cappell, 2008) and the research by Beurskens et al. (2014), if there were to be any age differences in step preparation performance and neural activity they would occur at levels of higher cognitive load. Furthermore, based on work by Coppin et al. (2006), any age impact

of cognitive control in stepping will depend not only on task load but also on the amount of environmental adaption and monitoring required. Accordingly, age differences in the effect that increased step decision making (simple/choice) has on PFC activity and Reaction Time (RT) should be greater when performing a more difficult secondary task compared to an easier secondary task. Therefore, an Age x Step x Task interaction was hypothesised. *Specifically, with increased step decision making demands (choice vs. simple step), under higher cognitive load, older adults' stepping RT would be lengthened and their PFC activity would be reduced compared to younger adults.* [1]

Method

Participants

Two cohorts were tested at the University of Tasmania Psychology Research Centre. The young healthy group (17 females, four males) ranged from 19-34 years of age (M_{age} = 26.9 years) and were recruited via posters distributed locally or through SONA (psychology research participation system). The second cohort consisted of healthy older participants (16 females, four males) and ranged from 62-87 years old (M_{age} = 69.4 years). This cohort were recruited from a research registry or via posters on local noticeboards. All participants were free from neurological conditions, free from muscle and joint pain with standing and walking and had no

[1] Note. According to the CRUNCH, what differs by age is the amount of change (PFC activity and performance) in response to increased task demands. To align results to this theory and assess if one age group increased *more than the other,* A PRIORI repeated contrast analyses were selected. Therefore, the hypothesis refers to an age differential impact of the step complexity on PFC activity and stepping RT when comparing an easier DT to a harder DT (higher cognitive load) – not age differences within the highest complexity condition only.

metal cranial implants. They were also free from cognitive or uncorrected visual impairment. Participation was voluntary, and participants were free to withdraw at any time. As renumeration, participants entered a draw to win one of two $100.00 Myers Gift cards or received course credit. The Tasmania Health and Medical Human Research Ethics Committee approved this study (Appendix A) and all participants provided written informed consent prior to participation.

Apparatus

FNIRS. The NIRSport system (NIRx Medizintchnik GmbH, Berlin) was used to collect hemodynamic data (ΔHbO_2) from the PFC. The flexible neoprene head band consisted of eight LED light sources (wavelength 760-850 nm) and seven detectors which covered the forehead using 22 channels. The distance between sensor and detector was 30 mm. This distance was chosen because greater than 20 mm in separation increases sensitivity of brain tissue, but with separation of greater than 40 mm, sensitivity starts to diminish (Strangman, Li, & Zhang, 2013). Data was sent to the NIRSport control box and sampled at a rate of 7.8125 Hz. A USB cable connected the control box to the laboratory laptop that ran NIRStar software (version 15.2) which calibrated channels and collected the data.

Force plates. Ground reaction forces were measured using two standing force plates (AMTI AccuSWAY, Massauchusetts, USA) which were calibrated prior to use. Signal analysis software (CED Signal, Cambridge UK) sampled data at 1000Hz. A digital trigger was sent at the beginning of each trial from the signal analysis software to both the NIRSport control box and the visual presentation computer to synchronise data collection (Figure 1). From the analogue force output (four vertical forces and four horizontal shear forces) Centre of Pressure (CoP) displacement was calculated and low pass filtered at 10 Hz.

Oscilloscope. A Tektronix TDS 210 two channel digital real time oscilloscope (60 MHz) with a maximum sampling rate of 1 Gs/s was used to assess balance and body position at the start of each trial. This real-time feedback to the experimenter ensured that the CoP of the standing participant was in the neutral, centred position prior to each trial commencing. This ensured no preloading horizontally or forward leaning occurred as this may have impacted RT.

Questionnaires. Questionnaires were completed before the experimental procedure began. Participants fear of falling was assessed using a paper based version of The Falls Efficacy Scale-International (FES-I) (Yardley et al., 2005). The FES-I asked questions about fear of falling when carrying out daily activities such as getting dressed or going to the shop (scored from 1- 4). It has good test-retest reliability (.96) and a Chronbach's alpha of .96.

Participants confidence in their balance was assessed using the Activities Specific Balance Confidence Scale (ABC) (Powell & Myers, 1995). This scale is highly stable over a two week period (r = .92) and has a Chronbach's alpha of. 96. To screen for cognitive impairment, versions of the Montreal Cognitive Assessment (MoCA) were used (Nasreddine et al., 2005). Alternative forms were required as some participants had completed the MoCA recently. The MoCA has good internal consistency, Cronbach's alpha of .83 and high test re-test reliability (r = .92). Although authors suggest a cut off of 26, the cut off of 23 was used as it has been found to have better specificity (Carson, Leach, & Murphy, 2017).

Secondary task selection. Secondary cognitive tasks for the Dual Task (DT) conditions chosen were; Forward Digit Recall (FDR) - an attention/working memory task which uses the phonological loop, and Backwards Digit Recall (BDR) an attention/working memory task that also uses that visuospatial sketchpad (Li &

Lewandowsky, 1995). The BDR task was selected as the more difficult task based on literature that visuospatial tasks have been rated as more difficult in Dual Task (DT) studies of balance (Walshe et al., 2015). Because working memory tasks such as FDR and BDR are well known for large individual and age-based differences (Dobbs & Rule, 1989) individualising digit span length was essential to ensure standardisation of the secondary task difficulty during the experiment. To achieve this, participants' forwards and backwards digit spans were initially measured sitting down via a computerised system using Inquisit software (Millisecond, Seattle). The two error maximal length measure was used as this is the traditional measure based on Woods et al. (2011).

Procedure

Participants were tested individually. Upon arriving, the study was explained to participants via the information sheet (Appendices B and C) and consent was gained (Appendix D). Health and relevant information were then collected using a general medical status sheet (Appendix E). If inclusion criteria were met, the FES-I, ABC, the MoCA, and forwards and backwards digit span tasks were completed. Following this, the experiment proper was conducted.

Set up. The experiment consisted of participants standing on a force plate (FP1) and stepping to another force plate (FP2) while wearing the fNIRS device (Figure 1). To minimise the risk of tripping, carpet squares were placed around the force plates until there was a raised area of approximately 150 cm by 150 cm. This area was delineated by caution tape around its perimeter. The experimenter was positioned close by for safety. In cases where the experimenter deemed falling may have been a risk, a walking frame was positioned in front of FP2 and a second researcher was present.

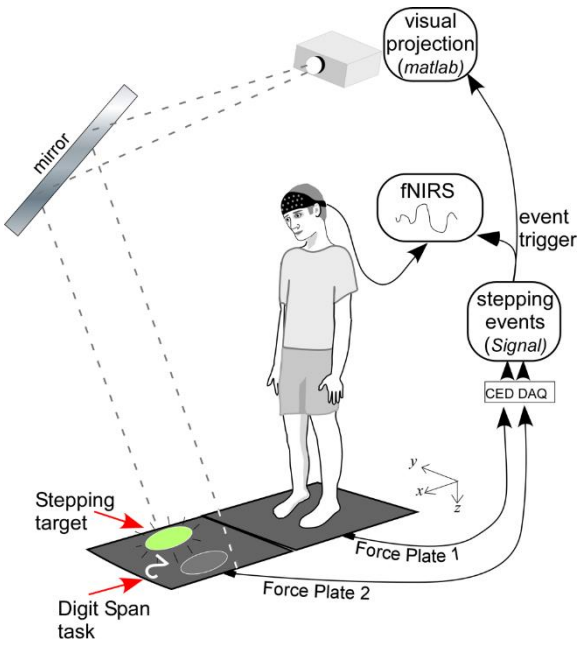

Figure 1. Experimental set up, drawn without walking frame or raised area for clarity. The projected image presented both the cue to step (left or right foot) and the digits to be recalled in the secondary tasks. Note: the stepping cue was always presented after all the digits, not simultaneously as shown in this illustration.

To ensure the starting position remained consistent between trials, foot placement (a self-determined comfortable stance) was traced on a white laminated sheet that was taped to FP1. The oscilloscope offset was adjusted to zero for the individual's stance position where they felt their weight was distributed between their feet. Prior to beginning each trial, the oscilloscope could then be reinspected to ensure the participant was in a similar stance to that previously assessed. Tasks were explained and participants performed up to three practice trials per condition. In DT practice trials where participants could not get any digit recall correct the number of digits to be presented was reduced one at a time until the task was manageable. This was to ensure that motivation to engage in the task remained.

The fNIRS device was then attached while the participant was seated. The device was placed on the forehead so that the horizontal symmetry axis central (y-

axis) was positioned between the eyes and the vertical axis positioned right above the eyebrows. As recommended by Huppert, Diamond, Franceschini, and Boas (2009), the cables were secured onto participants back (with tape) with lag taken up to reduce motion artefacts. The device was then calibrated.

Experimental procedure. Testing was carried out in a quiet room with lights dimmed slightly to allow a projected image on the force plate to be seen clearly. As Figure 1 depicts, an overhead projector was set opposite an angled mirror to direct the projected image onto FP2. MATLAB (R 2017b) software was developed to wait for the digital trial start trigger and Psychtoolbox generated the projected image of stepping targets and/or digits depending on the condition. Each trial in all conditions began with a 10 second baseline period when two grey shapes appeared on FP2. On this cue, participants focused on the FP2 and counted silently in their head – a frequently used procedure in fNIRS recordings to ensure standardised neural activity during the baseline period. Following this, depending on the condition, either the step cue was presented, or the presentation of the digits of the secondary task was initiated (for the DT conditions).

There were eight blocks of randomised conditions. Two blocks were cognitive only trials (FDR and BDR) for which participants were seated. Both trials presented digits to be remembered on FP2 at a rate of one digit per second. The same digit sequences were used across all participants (although sequences varied by length) and had been randomly generated and set to have no repeating numbers. Projected digit size was 10 cm vertically. Upon completion of digit presentation and following a 2 second pause, two green oval shapes appeared on FP2 (approximately a 20 cm x 15 cm) to alert participants to the end of the digit presentation, and to give

their answer. There were 10 trials in each block. Correctness was noted by the experimenter. Time to answer was not noted.

The FDR task was individualised to be a quarter less than participants assessed digit span (i.e. if a participant had a digit span of seven, they would be presented with five numbers to remember). The BDR task was intended to be more difficult so the experimental presentation was set to their backwards digit span (unless otherwise reduced in practice trials).

In all stepping conditions, base instructions were to "step as quickly as possible" and to "step your trailing leg on the force plate beside your stepping foot". Two blocks were stepping only tasks.

Simple Stepping (SS): There were 5 trials on the non-dominant leg, and then 5 on the dominant leg. Participants were told where the cue would be in advance and a small green dot also appeared in the middle of the cue location throughout the baseline period. This ensured there was no memory recall required for step limb and location during the baseline period.

Choice Stepping (CS): There were 10 trials for which the stepping cue appeared pseudo randomly on either the right or left side.

There were four DT trials: This was both stepping paradigms (SS and CS) combined with both levels of cognitive task (SS + FDR, SS + BDR, CS + FDR, CS +BDR). Figure 2 depicts how time presentation changes between single and DT conditions. In DTs, instructions were to "tell me the digits only when your trailing foot has completed the stepping task". This was to minimise artefacts from vocalisation in the fNIRS trace and ensured cognitive processes were engaged when the stepping cue was presented. Participants were instructed to step as quickly as possible and try their best at cognitive tasks.

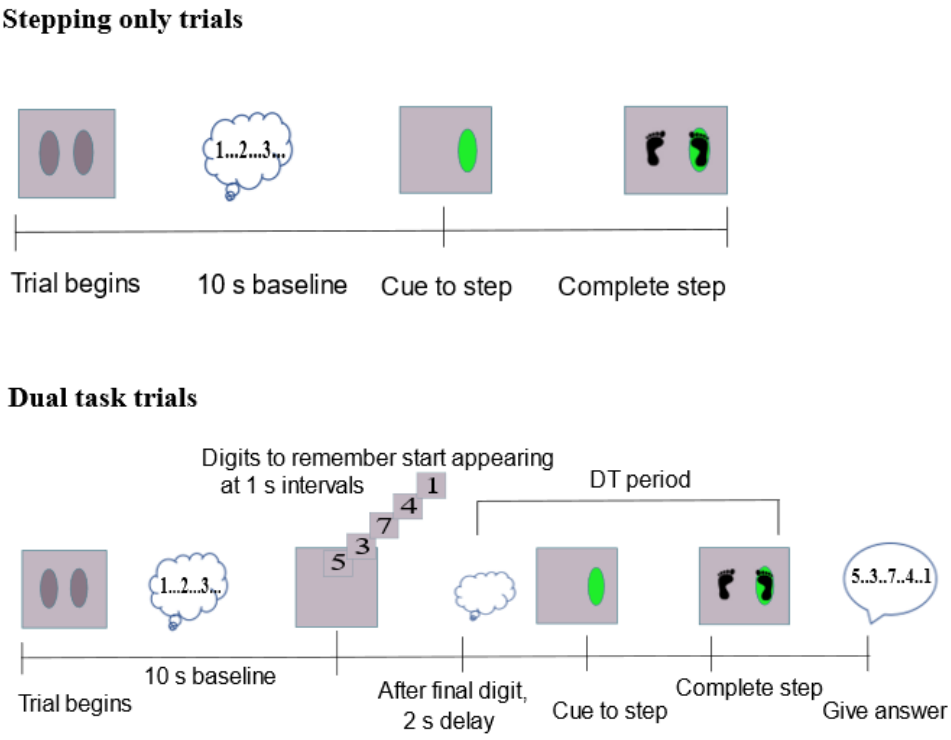

Figure 2. Trial sequence for the stepping only condition and DT conditions. The grey squares show the projected image to participants on FP2.

A reminder of the upcoming condition (e.g. forwards or backwards recall) was given before each trial as pilot testing indicated memory for the task instructions may be a confounding factor. Following the end of each trial, participants made their way back to the starting position in their own time. Immediately following the end of each block, the condition check, "how much cognitive effort did the prior task take?" was asked. Scores ranged from 1 (*not very*) to 5 (*extremely*).

In between each block, participants were offered a seated break, a drink and for the lights to be brightened if needed. In total, participation took approximately two hours and participants were debriefed upon completion.

Data Processing

Trials where step errors occurred or there was environmental distraction were deleted based on experimenter notes.

FNIRS data. To isolate cortical activity from motion artefacts and systemic noise, raw fNIRS data were converted to a MATLAB (R 2017b) compatible format (.nirs) so that HOMER2 (v2.8) add-on could be used. HOMER2 is a set of freely available MATLAB scripts designed to analyse fNIRS data. A series of processing steps were conducted. Initially channels where the signal intensity was too weak (<.001), too strong (>3), or the signal to noise ratio was too small were removed from further analysis ("enPruneChannels" function). Then raw light intensity data was converted to optical density ("hmrintensity 20D" function).

Next, a wavelet transformation of the optical density data removed motion artefact ("hmrMotionCorrectWavelet" function) (Molavi & Dumont, 2012) which has been shown to be particularly useful for verbal tasks (Brigadoi et al., 2014). The data were then band-pass filtered. High frequency components above .5Hz (such as fast cardiac oscillations) and low frequency components below .01 Hz (e.g. blood pressure oscillations) were removed.

Optical density was then transformed to concentration changes of HbO_2 and HHb using the modified Beer-Lambert approach (Delpy et al., 1988). Only HbO_2 concentrations were analysed further as they are a more reliable indicator of neural activity due to their superior signal to noise contrast (Strangman, Culver, Thompson, & Boas, 2002). Blocks of 10 trials were then averaged across the left and right DLPFC (Figure 3).

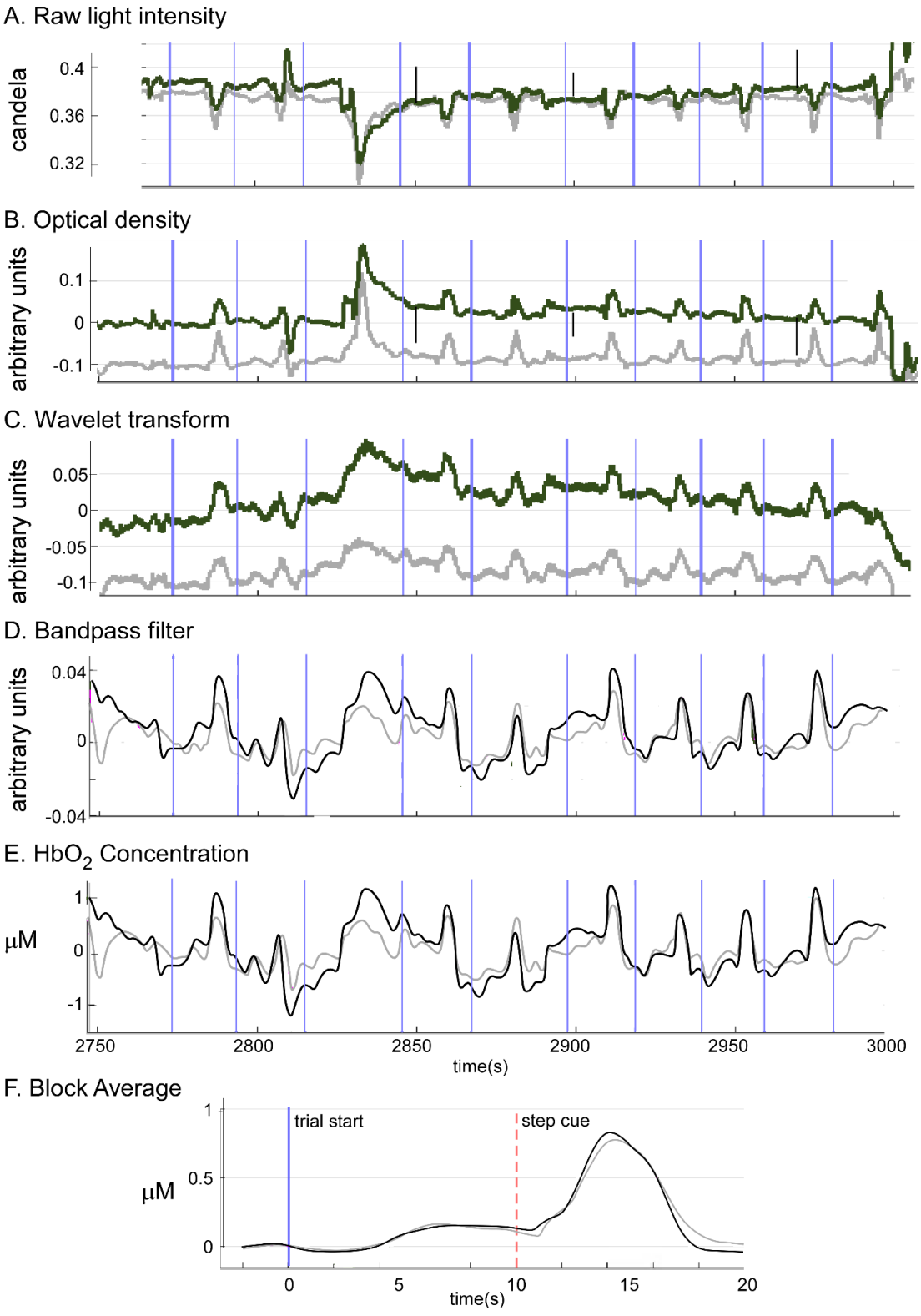

Figure 3. The signal analysis steps performed in HOMER2. The data is of 10 trials recorded of a younger adult in the CS condition. The black trace is activity from the left DLFPC (channel 14) and the grey trace is activity from the right DLPFC (channel 9). Vertical lines show the event trigger at the start of a new trial. In this condition the step cue was presented 10 seconds into the trial.

The 10 second mean baseline period prior to the cue was used to normalise data HbO_2 concentration waveform data. The peak response, following a period of sustained rise in ΔHbO_2 in the immediate 15 second window following step cue presentation was identified with a MATLAB algorithm. The area under the curve during this sustained rise in HbO_2 reflects the increase in neural processing so was calculated as the outcome variable of interest. Figure 4 shows how the area to peak ΔHbO_2 amplitude was calculated.

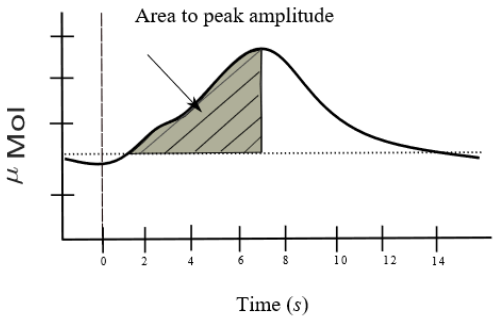

Figure 4. Outcome variable measurement - area to peak amplitude

Krampe et al. (2018) devised the topographical layout of the PFC using an identical fNIRS headband to that used in the current study. As shown in Figure 5 the channels 9 and 14 correspond to the Dorsolateral PFC. These areas were selected for analysis based on the relevant literature and in a bid to reduce activity from other non- hypothesised areas, such as motor cortex confounding results.

Figure 5. Topographical layout adapted from Krampe et al. (2018) which integrates the fNIRS 22 channels into which PFC regions the measurement sites correspond to. Dorsolateral area corresponds to areas 9 and 14.

Step reaction time. Trials where participants began step initiation prior to the cue or stepped with the wrong foot were excluded from analysis. The CoP (in the x and y directions) for each force plate were calculated (AMTI, 2005). All CoP data were low pass filtered at 100 Hz with a 4th order Butterworth filter.

Latency to first correct lateral APA was calculated when CoP (x) exceeded twice the *SD* of the signal. If there was an incorrect lateral APA associated with the step this was also noted if it exceeded twice the *SD* of the baseline signal. The posterior APA onset was also calculated when CoP (y) exceeded twice the *SD* of baseline. Latency to foot touch down was recorded when the vertical force on FP2 exceeded four times the *SD* recorded during the baseline period.

Figure 6 shows the identified parameters chosen by a MATLAB algorithm. Each trial was also plotted and visually inspected for correctness. In cases where the algorithm had chosen critical points incorrectly (e.g. when there was excessive standing sway in the baseline period) points were manually chosen.

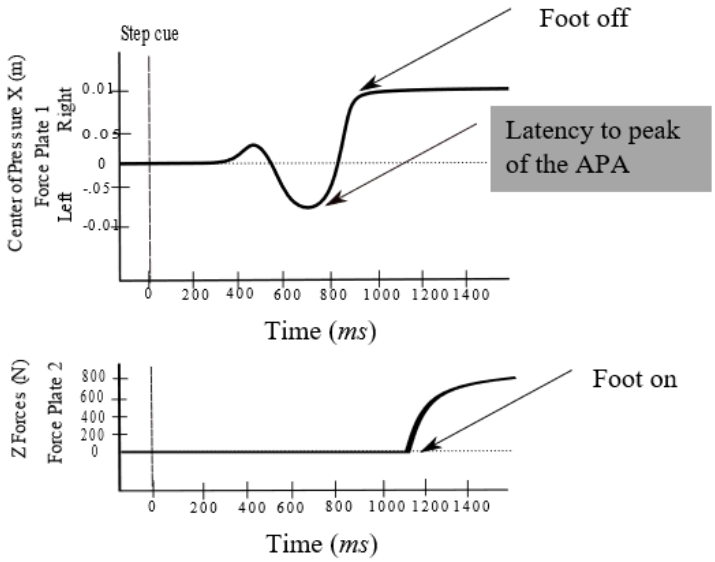

Figure 6. Measurement of critical step RT events. APA = anticipatory postural adjustment.

Design and statistical Analysis

A repeated measures ANOVA on step tasks (simple, choice) was employed to investigate the impact of limb selection on PFC activity for hypothesis one. For hypothesis two, to investigate the effect of age on stepping performance with increasing secondary task demands and step complexity, a 2 x 3 x 2 (Age [young, old]) x Secondary task [none, FDR, and BDR] x Step type [simple, choice]) mixed repeated ANOVA with the dependent variables: neural activity (area to peak amplitude) and step RT (RT to first APA) was assessed.

All analyses were conducted using IBM SPSS (version 26). As suggested by Maxwell and Delaney (2004), a Greenhouse-Geisser correction was applied to all analysis appropriate (indicated in text by the appearance of epsilon values). Partial eta squared (ηp^2) is given as a measure of effect sizes for main effects and interactions. Where necessary, higher order interactions were followed up with repeated contrast analysis (i.e. contrasting the stepping only condition to the FDR condition, and then contrasting the FDR to the BDR condition). To allow effect sizes to summarise a focused effect, *F* ratios for contrasts were converted into an *r* score. In these instances, effect sizes were interpreted as; $r = .01$ (small effect), $r = .3$ (medium effect), $r = .5$ (large effect) (Cohen, 1992).

Results

Assumptions

Before analysis of the research questions were conducted, data were analysed to ensure appropriate statistical assumptions were met. Dependent variables were inspected at separate age levels. As the sample size was not large ($n = 41$), the K-S test was deemed adequate to use for normality assessment.

Reaction Time data

Scores were visually inspected on a scatter plot, and outliers were removed if there was a clear reason in that particular trial. For example, if RTs were particularly long (> 3 *SD*s) relative to the mean RT of the participant, it suggested that attention was not on the task for the trail. Another reason for trial removal was if during the baseline period, postural sway had high variability due to fidgeting or large postural shifts, the critical points would be outside the algorithm parameters. When such trials were identified, the mean was taken from the remaining trials in the condition. Remaining outliers in the data were considered a genuine reflection of performance. A comparison of results with and without these remaining outliers revealed the outliers did not affect the results and were therefore left in.

Latency to correct APA was correlated with latency to foot touch down in each condition (ranging from $r = .77$, to $r = 9.15$, all $p < .001$). To reduce the number of behavioural outcome variables in the analysis, only latency to correct APA was used as the stepping reaction time outcome.

RT was normally distributed for all conditions except the CS + BDR, $D(20) = .22$, $p = .014$ in young adults. Log and square root transformations were trialled in order to normalise the distribution, however transformations resulted in greater issues to other conditions. Comparison of results with and without transformations were trialled and results did not differ, so the data remained untransformed. For two participants (one younger, and one older adult), in the SS + FDR condition the force plate recording failed therefore data in these trials is missing.

FNIRS data

Following plot inspections that highlighted extreme outliers, raw data was inspected and if there was a clear reason (e.g. too much noise), trials responsible were identified and removed. The participant mean was then taken over the remaining trials. Neural activity was not normally distributed for young adults in the SS condition, D (20) =.21, p = .026 and CS condition, D (20) = .27, p =.001, or the older adults in the CS + BDR condition, D (17) =.23, p = .019. Removing the outliers that may have affected the skewed distribution did not affect the result and were therefore left in. For three older adults, neural activity data was too noisy to be used. For one younger adult there was instrument error where data could not be converted.

Condition checks

Conditions checks were performed to ensure that the secondary cognitive task was standardised for each group. Both perceived difficulty ratings and accuracy of the secondary tasks were examined and found to have large skew and kurtosis. For accuracy data, the skew was negative for both age groups. Kurtosis was mainly negative for the younger adults and positive for the older adults. For effort ratings, the skew varied between negative or positive. In conditions with kurtosis, the kurtosis was positive for younger adults and negative for older adults. The Kruskal-Wallis nonparametric analysis was therefore used to carry out the necessary condition checks. As indicated by the means in Table 1, perceived cognitive effort of conditions did not differ by age group (p >.05 for all comparisons). There were no age group differences on accuracy of seated cognitive tasks (p > .05). Therefore, the standardisation procedure ensured cognitive task difficulty was consistent across groups.

Table 1

Young and Older Adults Means and Standard Deviations of Perceived Cognitive Effort to Complete Conditions

	Young adults $n = 21$		Older adults $n = 20$		Total $N = 41$	
Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*
FDR						
Sitting	2.10	.89	2.35	1.04	2.22	.96
SS+FDR	2.24	.89	2.43	.91	2.34	.90
CS+FDR	2.60	.80	2.48	.97	2.51	.85
BDR						
Sitting	2.90	1.02	3.39	1.09	3.16	1.06
SS+BDR	3.74	1.73	3.47	1.12	3.58	1.52
CS+BDR	3.48	.75	3.73	1.19	3.55	1.00
Stepping only						
SS	1.45	.68	1.73	.97	1.61	.86
CS	1.70	.80	1.82	.96	1.77	.89

Note. Perceived cognitive effort was rated on a Likert scale of 1 (*took no effort*) - 5 (*extreme amount of effort*).

Means of neural activity for the sitting cognitive tasks were analysed to assess whether the cortical area measured could differentiate between the 'hard' BDR, and the 'easier' FDR cognitive tasks. Differences in cognitive task difficulty could be detected with neural activity. The mean neural activity for the BDR sitting task ($M = .19$, $SD = .36$) greater than for the FDR sitting task ($M = .11$, $SD = .40$) although this did not reach significance $t\ (36) = 1.61$, $p = .117$. However, as the BDR task was rated as significantly more difficult than the FDR task, $T = 35$, $p < .001$ (analysed with a related samples Wilcoxon Signed Rank Test) the cognitive task complexity manipulation was deemed successful.

Covariates

Based on literature, the following demographics were potential covariates; FES-I score, ABC score, exercise per week (mins), and MoCA score. Table 2 highlights that means and *SD*s of participant scores and responses were relatively similar. No significant correlations were found between these potential covariates and either outcome variable therefore they were removed from the analysis are not further discussed.

Table 2

Means and Standard Deviations of Younger and Older Adults Demographic Scores

	Young adults $n = 21$		Older adults $n = 20$		Total $N = 41$	
Demographics	*M*	*SD*	*M*	*SD*	*M*	*SD*
ABC	93.80	5.52	94.17	3.87	93.98	.75
FESI	19.19	5.01	19.21	2.32	19.20	3.92
MoCA	27.15	3.57	26.75	2.29	26.95	2.97
Exercise	288	216	156	140	224	193

Note. ABC = Activities Balance Scale; FES-I = Fear of Falling-1; MoCA = Montreal Cognitive Assessment. Exercise (minutes per week) was a self-report estimate. If in the previous week participants had been unusually under or overactive, they were recommended to think of another week in the previous month.

Descriptive statistics

All participants were able to complete all tasks in full. Young adults had error trials (incorrect foot, early or late step etc) on 2 % of the stepping trials. Older adults had .9 % erroneous trials. RTs got slower for both young and older adults as secondary task increased in complexity (Table 3). The percentage of incorrect APAs associated with step trials were greater for both young and older adults for the choice step (Table 4). The mean number of digits required to be recalled in the FDR

conditions for young adults was 5.25 (*SD* =.77), and older adults was 4.80 (*SD* = 1.11). In the BDR conditions the mean number of digits required to be recalled for young adults was 5.52 (*SD* = 1.17) and older adults were 4.85 (*SD* = 1.35). Accuracy in the secondary cognitive tasks generally decreased as task difficulty increased (Table 5). Mean neural activity generally increased with the choice of step and secondary cognitive task for both young and old (Table 6).

Table 3

Means and Standard Deviations of Latency to Anticipatory Postural Adjustment of Younger and Older Participants (milliseconds)

	Young adults (n = 20)		Older adults (n = 19)		Total (N = 39)	
Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*
SS	464	32	450	58	457	47
SS+FDR	486	47	473	74	480	62
SS+BDR	487	50	547	154	516	116
CS	494	32	530	68	511	55
CS+FDR	505	43	526	71	516	59
CS+BDR	519	55	585	116	551	95

Note: Force plates had accuracy to one millisecond therefore measurements are not given to 2 decimal places.

Table 4

Percentage of Anticipatory Postural Adjustment Errors by Age, Step Type and Condition

	No added cognitive task		Forwards digit recall DT		Backwards digit recall DT	
Age	Simple	Choice	Simple	Choice	Simple	Choice
Young adults	0	7	1	4	0	8
Older adults	0	12	3	5	3	10

Table 5

Means and Standard Deviations of Younger and Older Adults Accuracy of Cognitive Tasks

	Young adults *n* = 21		Older adults *n* = 20		Total *N* = 41	
Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*
FDR						
SS	9.67	.56	9.65	.59	9.66	.58
CS	9.33	.58	9.70	.66	9.51	.64
BDR						
SS	7.48	2.40	8.25	1.97	7.85	2.21
CS	8.05	2.25	7.90	2.59	7.98	2.39

Note. The mean is the amount correctly answered, out of a possible score of 10

Table 6

Means and Standard Deviations of neural activity (ΔHbO_2 measured μ Mol) of Younger and Older Participants

	Young adults (*n* = 20)		Older adults (*n* = 17)		Total (*N* = 37)	
Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*
SS	1.62	1.34	1.71	.93	1.67	1.15
SS+FDR	2.03	1.44	2.19	1.35	2.10	1.38
SS+BDR	2.10	1.29	2.67	1.79	2.36	1.55
CS	1.74	1.48	2.06	1.13	1.89	1.32
CS+FDR	2.15	1.29	2.42	1.44	2.27	1.35
CS+BDR	3.74	1.83	2.47	2.05	3.16	2.02

Results for Hypothesis 1

A one way repeated measures ANOVA revealed that neural activity was greater for choice stepping (M = 1.89, SD = 1.32, 95% CI [1.44, 2.33]) than for simple stepping (M =1.67, SD = 1.51, 95 %CI [1.28, 2.05]), F (1 ,36) = 4.51, p = .041, ηp^2 = .11.

Results for Hypothesis 2

For RT data, Levene's test for equality of variances indicated that homogeneity of variances was violated in the following conditions; SS (p = .011), SS + BDR (p < .001), CS (p = .002), CS + FDR (p = .032), CS + BDR (p = .006). However, group sizes were relatively equal and the ratio of the largest age group variance to smallest age group variance was < 3 therefore analysis was continued. Conversely, in the neural activity data, Levene's test for equality of variances indicated that homogeneity of variances was met for all conditions. Box's M was not significant at α < .001 for either neural activity or RT data.

There was no main effect of age on RT, F (1,37) = 1.82, p = .186, ηp^2 = .047 or neural activity, F (1,35) =. 01, p =.940, ηp^2 < .001.

There was a main effect of the secondary task complexity on RT, F (1.34, 49.60) = 16.16, p <.001, ηp^2 =.30. ε =.67. RTs became slower as task complexity increased. There was also a main effect of secondary task on neural activity, F (1.56, 54.12) = 10.23, p < .001, ηp^2 =.23, ε = .77 with neural activity increasing as task complexity increased.

RTs increased when there was a choice of step, indicated by the main effect of step type, F (1, 37) = 44.56, p <.001, ηp^2 = .55. RTs for the CS conditions (M = 526 ms) were slower than for the SS conditions (M = 484 ms). Neural activity was also greater for the CS conditions (M = 2.38) compared to SS conditions

(*M* = 1.97) when averaging over secondary task complexity and age (indicated by the significant main effect of step), *F* (1,35) = 9.52, *p* = .004, ηp^2 = .21.

The Step x Age interaction on RT was significant, *F* (1, 37) = 5.71, *p* = .022, ηp^2 = .13. The significant contrast (*r* = .44) and interaction graph shown in Figure 7 indicates that although RT slows for both age groups, when comparing simple to choice stepping, the decrease in speed was relatively larger for older adults. The Step x Age interaction on neural activity was also significant, *F* (1, 35) = 4.37, *p* = .044, ηp^2 = .11.

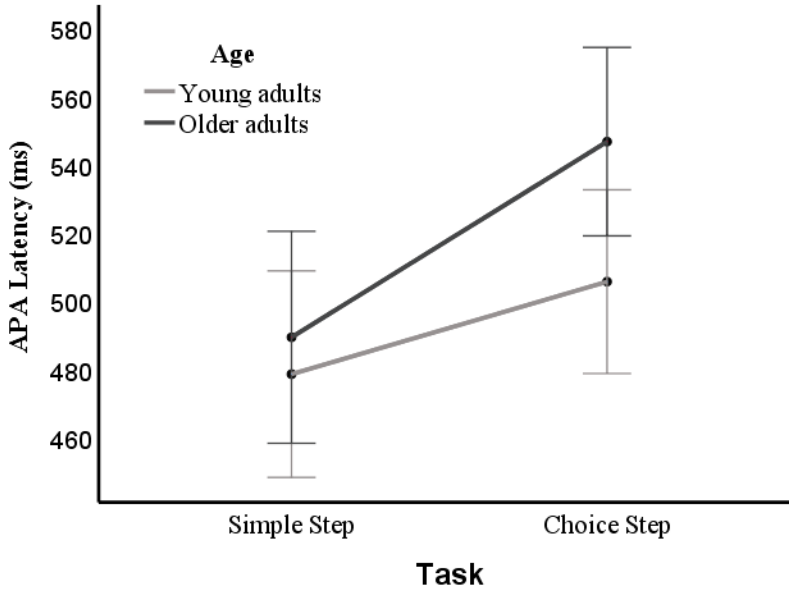

Figure 7. The interaction of age and step on the step RT (APA latency). Means are averaged across secondary task complexity. Error bars represent 95 % CIs.

As shown in Figure 8, stepping RTs changed as a function of secondary task and age (significant Age x Secondary task interaction), *F* (1.34, 49.60) = 6.28, *p* = .009, ηp^2 = .15, ε = .67. Repeated contrasts revealed that when comparing older adults to young adults, when comparing the stepping only task to the FDR DT there was no RT difference, *F* (1, 37) = .47, *p* = .497, *r* = .11. However, when comparing the FDR DT to the BDR DT, there was a significant interaction. *F* (1, 37) = 8.18,

p = .007 and this was a moderate to large effect, r = .43. RT slowed as cognitive task complexity increased, however the slowing was significantly more pronounced when participants were older.

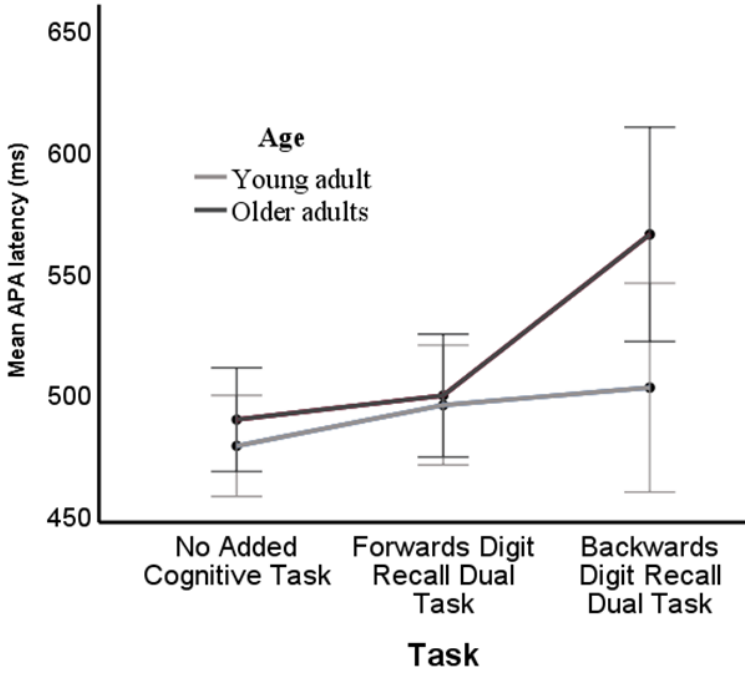

Figure 8. The interaction of age and task on step RT (APA latency). Means are averaged across step types. Error bars represent 95 % CIs.

Age groups did not differ in the amount of neural activity in response to secondary tasks when averaging over step type (non-significant Age x Task interaction on neural activity), F (1.55, 54.12) = 1.14, p = .317, ηp^2 = .03, ε = .77

Important to Hypothesis 2, the Age x Task x Step interaction on RT was not significant, F (1.60, 59.20) = 1.73, p = .189, ηp^2 =.05, ε = .80. Conversely, the Age x Task x Step interaction on neural activity was significant, F (1.37, 48.05) = 9.37, p <.001, ηp^2 .21, ε = .69. As indicated by Figure 9, the effect that step complexity had on neural activity was dependent on secondary task complexity and age. Contrast analysis was used to break down this interaction.

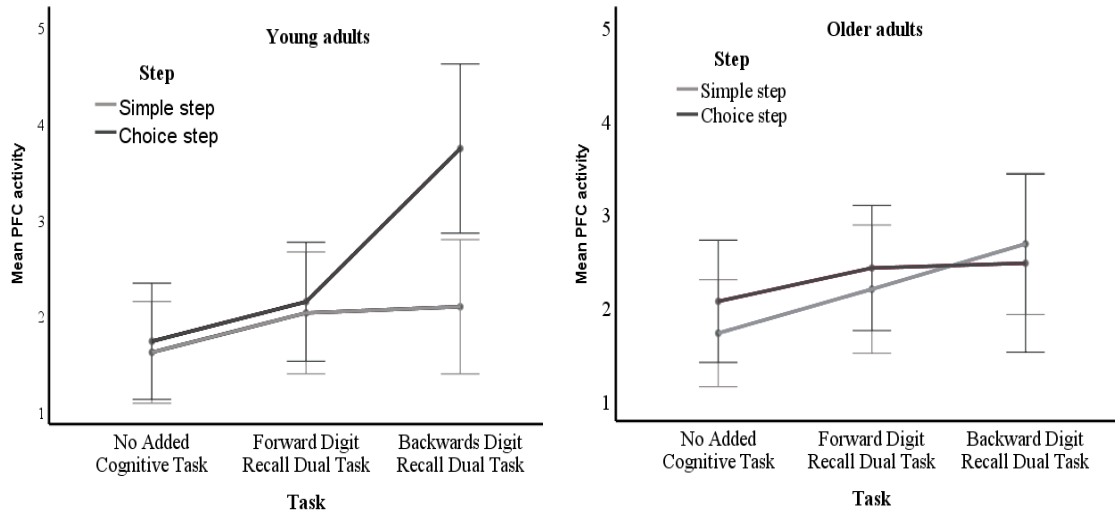

Figure 9. Differences in Mean neural activation (measured in ΔHbO_2) by step and cognitive condition across age groups. Bars represent 95% CIs.

Contrast 1: Comparing the no cognitive to the FDR DT condition.

Neural activity increase for a choice compared to a simple step was the same between age groups regardless of whether it was a stepping only task or stepping with FDR (non-significant contrast), F (1, 35) = .14, p = .710, r = .06.

Contrast 2: Comparing the FDR DT to the BDR DT condition.

The effect of being older on neural activity when comparing a choice to simple step was significant, F (1, 35) = 9.84, p = .003, r = .47. Specifically, for a simple step, neural activity was similar whether it was for the FDR or BDR secondary task and this was similar whether adults were older or young. For a choice step, in older adults, neural activity was the same regardless of secondary task. Whereas, for the choice step in the young adults, activity was much higher in BDR than in FDR secondary task.

Additional Analysis - Examination of Neural Activity Latency to Peak

Figure 10 shows that there was an unexpected difference in latency to peak neural activity in some conditions. Latencies in fNIRS data are not generally reported

in the literature, however in the current data the experimental conditions were clearly affecting the latencies of the peak responses. Although unconventional to analyse variables if not hypothesised, in a bid to understand if the observed latency to peak would impact inferences made about hypothesised results, latency to peak was analysed as an outcome in the model. Results are reported in Appendix E.

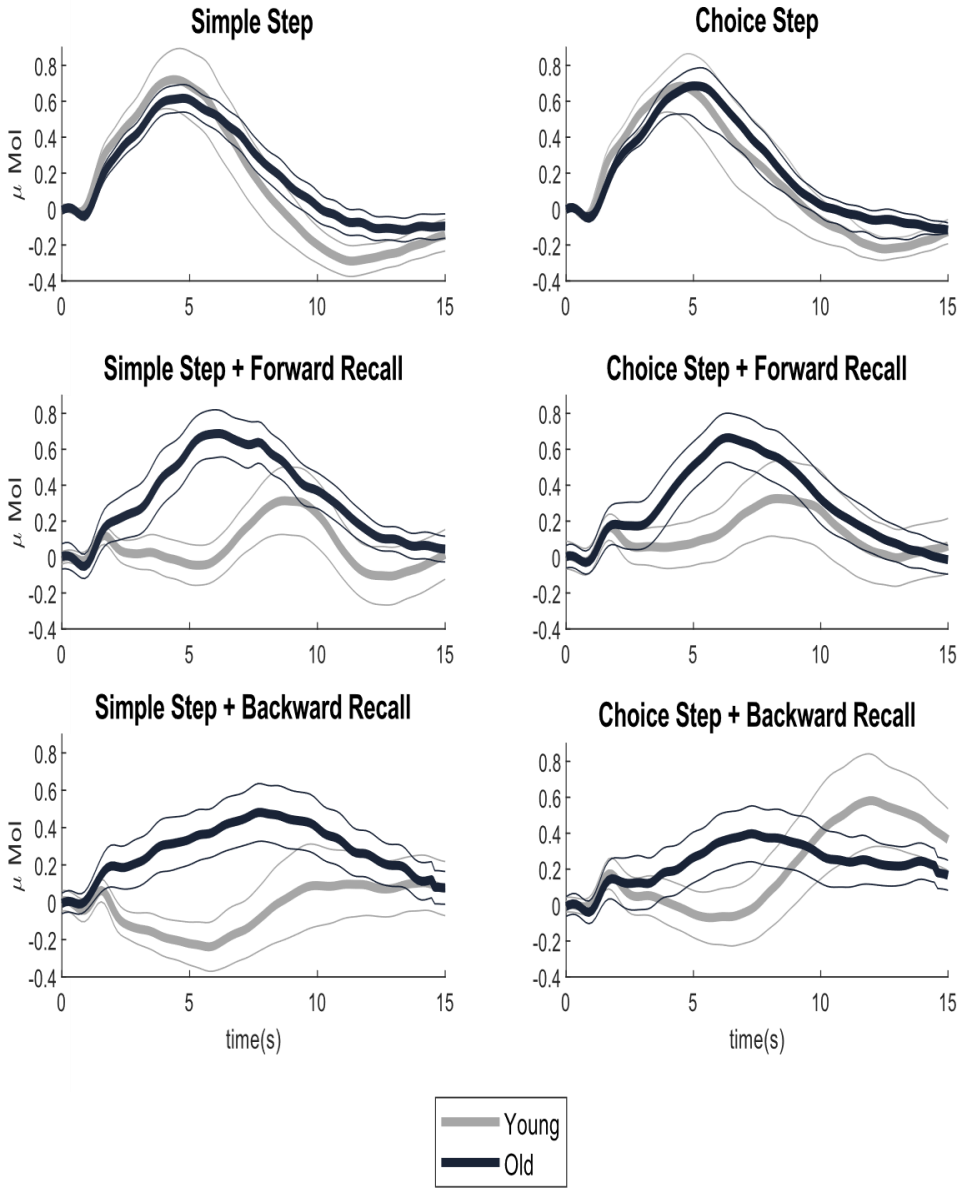

Figure 10. Mean traces of young and older adults' neural activity in response to task and step condition. Thin lines represent standard error. Zero is when the stepping target was illuminated.

Discussion

The aim of the current study was twofold: to investigate the role of the PFC in initiating a step to a visual target, and to observe any age-related changes due to step and secondary cognitive task complexity. The first hypothesis, that the PFC would increase in neural activity more for a choice step than a simple step, was supported by the data. 11% of the variance (and its associated error) accounted for the effect. The significant result provides the neural correlates of the cognitive control required to select the correct stepping leg as proposed by Cohen et al. (2011). Therefore, one of the roles that the PFC may play in gait is decision making and response monitoring of the environment to initiate a step with the most appropriate foot. This adds to the current understanding of gait where currently the role of PFC is not well understood.

Applying our findings to existing literature, the PFC involvement required for monitoring where to step may help to explain the increased cortical activity seen in more complex gait tasks. For example, in the precision stepping study by Koenraadt et al. (2014), the increased cortical activity observed for precision stepping could in part be due to increased response monitoring and decision making required to complete the task.

The second hypothesis that step decision requirements would impact the response of older adults more during a demanding secondary cognitive task was partially supported. The fNIRS results supported the hypothesis evidenced by a significant three-way ANOVA. When cognitive load increased to stepping while also performing the BDR task, the young adults had more pronounced neural activity for the choice step compared to the simple step. This is in line with the CRUNCH view that young adults upregulate activity in the PFC when task demands are high.

Proponents of the CRUNCH would also predict that the increased neural recruitment would be of benefit to performance; with stepping RT of the CS in young adults less impacted than the older adults during higher task loads. While it was indeed the case that young adults did not significantly slow for the choice compared to the simple step under higher task load, caution in interpretation is required. The separate behavioural and neurophysiological correlates are only co-occurring. It cannot be asserted that the increased activation *was* responsible for the maintenance of performance. Future research could investigate whether increased activation prior to step initiation in choice response paradigms is in fact compensatory for faster step latency. For example, activity prior to successful limb selection (i.e. in a choice step paradigm with no APA errors made) in comparison to erroneous limb selection could be investigated. If compensatory, and greater activation results in better performance, successful trials would be related to greater activation. Although not examined in stepping research, a similar paradigm has been investigated in word recall. Older adults who did not increase activation compared to younger adults performed poorer on word recall. However, the older adults who had greater activation were more successful (Cabeza et al., 2002).

Conducting analysis comparing correct to incorrect trials was not feasible with the current data set as the percentage of APA errors were very low. The highest percentage of APA errors in conditions for older and younger adults were 12 % and 8 % respectively. As the number of trials in each condition was also low (n =10), it was deemed that if further analysis was run on this small amount of data, results may be unrepresentative. Investigations using more trials would be beneficial. Moreover, greater step complexity, such as a four choice paradigm (see Lord & Fitzpatrick,

2001) may induce more APA errors. This would help further understand the neural correlates of slower stepping related to fall risk.

RT data did not support the hypothesis that step, cognitive task complexity and age would all interact. However, averaging over task complexity, choice stepping did hinder older adults' RT more than young adults which is similar to the findings of Cohen et al. (2011). This suggests that one of the ways that cognitive control of step initiation changes with age is that older adults are more hindered by the increased demands of needing to monitor where is appropriate to step. While this has been inferred through object navigation studies e.g. Coppin et al. (2006), in object navigation studies such as these, biomechanical age differences cannot be disentangled from cognitive control differences. In our study, only the movement preparation time was analysed. Therefore, it can be robustly concluded that differences in younger and older adults were due to the decision time rather than the movement time. Age related deficits in stepping speed when environmental adaption was required occurred in the perceptual and motor preparation phase.

The lack of RT difference due to increased step complexity (simple to choice) under high cognitive load is curious considering the research by Coppin et al. (2006) indicating that gait complexity strains older adults and this effect is increased under cognitive load. One explanation is that older adults may have reduced the demands on cognitive control in the harder condition by slowing for *both* simple and choice stepping conditions. Evidence for this can be gleaned from the significant Age x Secondary task interaction. When comparing the FDR (easier DT) to the BDR (harder DT) conditions, averaging over step types, older adults had significantly delayed step initiation reaction times compared to young adults.

A similar ‘conservative stepping strategy’ is observed when older adults step over obstacles. Chen, Ashton-Miller, Alexander, and Schultz (1991) found that although older adults had comparable obstacle clearance, the older adults implemented a more cautious strategy where they crossed the obstacle at a slower speed and used a shortened crossing step length. When the number of APA errors that occurred in our study were analysed, further support for the slowing strategy in older adults in the BDR DT is garnered. There were no more errors for the BDR condition than the FDR conditions in simple stepping yet a large increase in reaction time for the BDR condition was seen. The slowed RT therefore was not due to performing more limb selection errors. The slowing may have helped reduce the impact of step uncertainty or bought the older adults more time before responding.

Although slower stepping speed is related to fall risk (Lord & Fitzpatrick, 2001), being conscious of the internal and external environment and making appropriate judgements could be adaptive and a sign of good EF (Yogev et al., 2008). For example, monitoring one’s ability and slowing when walking on loose gravel may reduce the risk of harm. Therefore, if in fact a more cautious strategy was taken, whether it is related to more or less risk of falling requires further investigation.

In a similar vein, whether older adults would still slow their stepping under the cognitive load of visuospatial processing if there were greater threats to posture needs further investigation. For example, Brown, Sleik, Polych, and Gage (2002) showed that when younger and older adults performed a spatial task under different levels of postural threat, more older adults swapped to prioritising their posture task before the cognitive tasks.

As opposed to a conscious decision, a second rationale for the slowed stepping in older adults during the BDR may be cognitive interference. Both tasks may have been competing for similar cognitive resources (Kahneman, 1973). This is based on the premise that BDR uses visuospatial processes (Li & Lewandowsky, 1995) and postural control places demands on visuospatial processing (Kerr, Condon, & McDonald, 1985). Moreover, cognitive tasks involving visuospatial processing have been found to impact older adults postural control more than young adults (Maylor & Wing, 1996). It is thought that manipulating visuospatial information might reduce the ability of older adults to use visual information to control postural stability (Maylor & Wing, 1996). Our findings support this - older adults' step initiation was comparable when performing a non-visuospatial memory task (FDR), but was impacted when performing a visuospatial memory task (BDR).

Our results, that older adults were more impacted by visuospatial demands than young adults mimics Beurskens et al. (2014) treadmill study and not only supports findings by St George et al. (2007) but furthers them due to the stepping complexity modulation used. In our study, not only was choice stepping in the older adults hindered by a visuospatial task, even stepping to a known location was significantly slowed.

Taken together, these findings suggest that older adults could maintain comparable stepping and PFC involvement up until executive functions were strained through either increased step decision making or higher cognitive load. This finding firmly supports criticisms by Walsh et al. (2015) that a failure to use tasks that strain EFs creates ambiguity and inconsistency in findings. Our results show that noting differences between a single task and one DT, as regularly conducted in research would yield conflicting results as results would depend on the DT used.

Clinical Implications

It is apparent from the results that when older adults perform dual tasks, particularly of a visuospatial nature, stepping responses to environmental cues are impaired. Furthermore, the pattern of neural activity increases observed in the young group during the choice step BDR condition suggests that upregulation of the PFC activity may help to maintain fast step initiation when under high cognitive load. Critically, for older people at risk of falls, the PFC is amenable to neuroplastic changes with training. DT training programs are being trialled to reduce the negative impact of dual tasking in older age. For example, Erickson et al. (2007) investigated the neuro-plasticity associated with EFs by examining RT performance and neural correlates of DT training. Results indicated that most areas that were active while dual tasking pre-intervention were reduced post intervention (indicating decreased cognitive resources required to perform dual tasking) (Erickson et al., 2007). Training also increased activity in dual tasking in the DLPFC which was related to faster reaction times. Furthering this research, the focus of which tasks are the most hindering is important to clinical application.

For example, Plummer-D'Amato et al. (2010) trialled a DT training program with gait and object navigation and concluded that the training program did not improve DT cost or object navigation. However, the tasks used were largely verbal responding tasks (e.g. alphabet recall) that did not require visuospatial processing. Based on the findings of the current study, the mildly attentionally demanding DT used by Plummer-D'Amato et al. may not have been enough to challenge or improve performance. Future training paradigms to improve PFC function should consider the use of visuospatial processing as well as tasks that require navigation and adaption in movement.

Limitations

A notable limitation of fNIRS research is that the temporal resolution of the hemodynamic response is poor due to the delay in the hemodynamic uptake. Length of delay ranges in literature from 4 to 5 seconds after starting a motor or cognitive task (Villringer & Chance, 1997) up to 7 seconds (Vitorio, Stuart, Rochester, Alcock, & Pantall, 2017). While this is not a concern in steady state gait studies (because mean activity is taken), localising the activity that occurred in a small time window is challenging. Therefore, it cannot be explicitly confirmed that the PFC activity being captured originated from the exact time period prior to step initiation.

Importantly though, our experimental design was based on the recommendations by Vitorio et al. (2017) that manipulations of similar tasks increasing in complexity yields the most valid results. Specifically, in our study, simple to choice stepping was contrasted. The motoric response was identical: the only thing modulated was whether participants knew where to step in the step preparation stage. Therefore, although localising the activation for the step initiation is challenging, it can be asserted with confidence that the changes in neural activity corresponded to the step preparation phase as everything else was held constant.

An unexpected difference in the time to the peak hemodynamic response was observed between conditions and ages (Appendix F). There is yet no consensus in the fNIRS literature on the most appropriate metric to extract from the waveforms and indeed it may need to vary according to the task tested. In the current study, the area under the curve to the peak amplitude of the ΔHbO_2 was used. Because area was only calculated for the continuous rise time (which reflects increased blood flow) this did not disadvantage either age group if there was a time delay to peak response. Therefore it is unlikely that the latency difference impacted hypothesised results or

inferences made. However, because temporal differences were noted in the current study, caution is required in comparing results to other research using a different metric.

Because of the above-mentioned time lag and latency to peak observations, other more complex analysis such as area under the curve within multiple time windows could clarify findings further. Future studies could also refine the procedure by using fNIRS in conjunction with Electroencephalography (EEG). Signals of both devices could be synchronised which could offer a uniform recording of time measurement (Berger et al., 2019). EEG has successfully been used to investigate the preparation of a step (Velu & de Sa, 2013), and EEG and fNIRS have been successfully paired in a language study (Wallois, Mahmoudzadeh, Patil, & Grebe, 2012). Moreover, fused fNIRS and EEG has been recommended for use in other gait rehabilitation programs (Berger et al., 2019).

Conclusion

The current study has made an important step towards understanding the role that the PFC plays in gait – monitoring the environment to initiate stepping with the appropriate leg. Further to this, it made meaningful contributions to research by applying neurocognitive aging theory to step initiation. Our results provided support that cognitive load does impact the behavioural and neurophysiological correlates of step preparation differently for young and old. The older adults employed slower stepping strategies, whereas the younger adults were able to more flexibly engage the PFC and maintain fast stepping.

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Appendices

Appendix A: Ethics Approval Letter

Dear Dr St George,

Ethics Ref: H0014865
Title: Age-related changes in the cerebral cortex for human balance

This email is to confirm that the following amendment was approved by the Chair of the Tasmanian Health and Medical Human Research Ethics Committee on 26/4/2019:

Amendment Remove Staff: Eliza Walker
Amendment Additional Staff: Danielle Pretty
Information Sheet Older Participant Information Sheet V6 - 21Mar2019 Protocol Study Protocol V4 - 21Mar2019

All committees operating under the Human Research Ethics Committee (Tasmania) Network are registered and required to comply with the National Statement on Ethical Conduct in Human Research (NHMRC 2007, updated 2018).

Please be reminded that all ethical approvals granted are subject to conditions as required by the National Statement. A copy of the conditions of approval is available at http://www.utas.edu.au/research-admin/researchintegrity-and-ethics-unit-rieu/human-ethics/human-research-ethics-review-process/managing-your-ethicsapproved-projects

Kind regards,

Gina Zappia

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Appendix B: Older Participant Information sheet

OLDER PARTICIPANT INFORMATION SHEET

(Version 6 March 21 2019)

Age-related changes in the cerebral cortex for human balance

You are invited to participate in a study investigating age-related change in cortical activity when people are standing, walking or performing balance tasks.

The study is being conducted by:

- Dr Rebecca St George, School of Medicine, University of Tasmania
  Email: Rebecca.StGeorge@utas.edu.au
  Phone: 03 6226 2558

- Danielle Pretty, School of Medicine, University of Tasmania.
  Email: danielle.pretty@utas.edu.au

The study will be conducted at: The Cognitive and Motor Aging Laboratory, Psychology Research Centre, Sandy Bay Campus, University of Tasmania, (03) 6226 2887.

'What is the purpose of this study?'

The aims of the project are firstly to investigate how sensory input is processed by the cortex to control balance, and secondly to understand how the cortical contributions to standing balance change with age. An increased understanding of these neural processes may lead to improved rehabilitation and treatment for people with balance disorders.

'Why have I been invited to participate in this study?'

You are invited to participate if you are either male or female and over the age of 60 and have no known neuromuscular or neurological disorders, or joint or muscle pain when standing.

Cortical Activity will be recorded with Functional Near Infrared Spectroscopy (fNIRS). **fNIRS** carries no risk to any participant although people with metal implants in the head will be excluded as this may alter the quality of the recording.

Certain medications (for example some types of anti-depressant medications) can influence how the brain responds to sensory stimulation and voluntary movements. *Therefore, we ask that you inform the researcher if you are taking any medication prior to participating in the study*.

'What if I don't want to take part in this study, or if I want to withdraw later?'
Participation in the study is completely voluntary. If you agree to participate, you are free to withdraw from the study at any time without prejudice. You can decide to terminate your participation at any point without giving a reason. If you decide not to participate, it will not affect your relationship with the University of Tasmania in anyway. If you withdraw from the study, any data that you have supplied can be identified through the alpha-numeric coding system and withdrawn from the study if you wish.

'What does this study involve?'
You will be asked to attend one session lasting up to 2 hours. Every effort will be made to schedule the session at a mutually convenient time. Parking will be provided. At the beginning of the session you will meet the researchers and they will explain the procedure to you and you will have the opportunity to ask any questions you may have.

This study will involve:

- Being asked questions regarding your physical health, to ensure that you will not be exposed to any avoidable risks as part of participation in this study.
- Signing a Participant Consent Form
- Performing a brief (10 minute) cognitive screening test (Montreal cognitive assessment). The results of this test will be made available for you.
- Standing balance tasks and walking will be performed while brain activity is measured with Functional Near Infrared Spectroscopy.

Standing and Walking Tasks: The experimenter will provide you with the specific details relating to your study prior to participation. You will be asked to perform some of the following standing and walking tasks.

1. You may be asked to stand still and then step on to a visual target presented on the ground. Stepping may be with your left or right foot and in some trials the target may change position.
2. You may be asked to stand either in your normal posture, or with your feet together or wider apart.

In some trials you will be asked to perform cognitive tasks such as count backwards, remember numbers or recite alternate letters of the alphabet.

To ensure safety, a researcher will be standing close by to offer stability if required. If you feel too unsteady the trial can be aborted. To minimize fatigue from prolonged standing you will take seated rest breaks every minute or so. The testing time, including breaks is approximately one hour.

fNIRS. You will wear a light-weight headband that wirelessly transmits (via Bluetooth) information about your brain activity. fNIRS measures changes in the oxygenation level of the blood flow at the cortex which reflects the neuronal activity. This is a safe, passive technique that measures the tissue interaction properties of light within the near infrared range. There is no radiation, and no discomfort.

'How is this study being paid for?'

This research is funded by a grant from the National Health and Medical Research Council (NHMRC: APP1036234).

'Will taking part in this study cost me anything, and will I be paid?
Participation in this study will not cost you anything. You will go in a draw to win one of two $100 Coles/Myer vouchers.

'Are there risks to me in taking part in this study?'
You may experience some fatigue due to standing. If you become uncomfortable please inform the researcher and more rest breaks can be given or the procedures can immediately be stopped.
There may also be risks associated with this study that are presently unknown or unforeseeable.

'What happens if I suffer injury or complications as a result of the study?'
In the unlikely event that you suffer any injuries or complications as a result of this study, you should contact Dr St George as soon as possible on 03 6226 2887, who will assist you in arranging appropriate medical treatment.

'Will I benefit from the study?'
It is unlikely that you will benefit personally from participating in this research project, but the results will help our understanding of some basic functions of the healthy human brain. Indeed, we hope that the results of this study will eventually help us to treat impairments in balance associated with aging and neurological diseases.
'How will my confidentiality be protected?'
Your individual experimental data will be coded alpha-numerically and stored on a secure computer server that will be available only to the investigators via a password system. All future use of your data will be by the alpha-numeric code only to ensure anonymity. Your data will be retained securely at the University of Tasmania for at least five years. When it is no longer required by law, your data will be destroyed by the deletion of electronic files and shredding of documents.

You will be asked to sign an informed consent form to evidence your consent to participate in the study. Consent forms will be locked in a filing cabinet in the Cognitive and Motor Aging Laboratory at the University of Tasmania and kept separately from your data.

'What happens with the results?'
All data will be presented anonymously in any publications arising from this study. If you wish to be notified on the results of this study, please feel free to contact us.

'What should I do if I want to discuss this study further before I decide?'
If you have any queries, concerns or issues with this study at any time, please feel free to contact us:

Dr Rebecca St George (03 6226 2887 or Rebecca.StGeorge@utas.edu.au)

'Who should I contact if I have concerns about the conduct of this study?'
This study has been approved by the Tasmanian Health & Medical Human Research Ethics Committee. If you have concerns of complaints about the conduct of this study you should contact the Executive Officer of the HREC (Tasmania) Network on (03) 6226 6254 or email human.ethics@utas.edu.au. The Executive Officer is the person nominate to receive complaints from research participants. You will need to quote ethics reference number **H0014865**.

You will be provided with a copy of this information sheet and a statement of informed consent to keep. When finalized, results of the study will be posted on the University of Tasmania website, . It can be expected that results of individual studies will be available within a year of data collection.

Thank you for taking the time to consider this study.
If you wish to take part in it, please sign the attached consent form.
This information sheet is for you to keep.

Appendix C: Younger Participant information sheet

YOUNG PARTICIPANT INFORMATION SHEET

(Version 5 March 21 2019)

Age-related changes in the cerebral cortex for human balance

You are invited to participate in a study investigating age-related change in cortical activity when people are standing, walking or performing balance tasks.

The study is being conducted by:

- Dr Rebecca St George, School of Medicine, University of Tasmania
  Email: Rebecca.StGeorge@utas.edu.au
  Phone: 03 6226 2558
- Danielle Pretty, School of Medicine, University of Tasmania.
  Email: danielle.pretty@utas.edu.au

The study will be conducted at the Cognitive and Motor Aging Laboratory, Psychology Research Centre, Sandy Bay Campus, University of Tasmania, (03) 6226 2887.

'What is the purpose of this study?'
The aims of the project are firstly to investigate how sensory input is processed by the cortex to control balance, and secondly to understand how the cortical contributions to standing balance change with age. An increased understanding of these neural processes may lead to improved rehabilitation and treatment for people with balance disorders.

'Why have I been invited to participate in this study?'
Individuals (male and female) between 18 and 35 years of age are invited to participate in this research. Interested volunteers should have no known neuromuscular or neurological disorders, or recent pain or discomfort associated with standing.

Cortical Activity will be recorded with Functional Near Infrared Spectroscopy (fNIRS). **fNIRS** carries no risk to any participant although people with metal implants in the head will be excluded as this may alter the quality of the recording.

Please ask the experimenter if you are unsure of any of these.

Certain medications (for example some types of anti-depressant medications) can influence how the brain responds to sensory stimulation and voluntary movements. *Therefore, we ask that you inform the experimenter if you are taking any medication prior to participating in the study*.

'What if I don't want to take part in this study, or if I want to withdraw later?'

Participation in the study is completely voluntary. If you agree to participate, you are free to withdraw from the study at any time without prejudice. You can decide to terminate your participation at any point without giving a reason. If you decide not to participate, it will not affect your relationship with the University of Tasmania in anyway. If you withdraw from the study, any data that you have supplied can be identified through the alpha-numeric coding system and withdrawn from the study if you wish.

'What does this study involve?'

You will be asked to attend a session lasting up to 2 hours. Every effort will be made to schedule the session at a mutually convenient time. At the beginning of the session you will meet the researchers and they will explain the procedure to you and you will have the opportunity to ask any questions you may have.

This study will involve:

- Being asked questions regarding your physical health, to ensure that you will not be exposed to any avoidable risks as part of participation in this study.
- Signing a Participant Consent Form
- Performing a brief (10 minute) cognitive screening test (Montreal cognitive assessment). Results of this test will be provided to you.
- Standing balance tasks and walking will be performed while brain activity is measured with Functional Near Infrared Spectroscopy.

Standing and Walking Tasks: The experimenter will provide you with the specific details relating to your study prior to participation. You will be asked to perform some of the following standing and walking tasks.

1. You may be asked to stand still and then step onto a visual target presented on the ground. Stepping may be with your left or right foot and in some trials the target may change position.
2. You may be asked to stand either in your normal posture, or with your feet together or wider apart. In some trials you will also be standing on a piece of foam or on a raised platform.

In some trials you will be asked to perform cognitive tasks such as count backwards, remember numbers or recite alternate letters of the alphabet. To ensure safety, a researcher will be standing close by to offer stability if required. If you feel too unsteady the trial can be aborted. To minimize

fatigue from prolonged standing you will take seated rest breaks every minute or so. The testing time, including breaks is approximately one hour.

fNIRS. You will wear a light-weight headband that wirelessly transmits (via Bluetooth) information about your brain activity. fNIRS measures changes in the oxygenation level of the blood flow at the cortex which reflects the neuronal activity. This is a safe, passive technique that measures the tissue interaction properties of light within the near infrared range. There is no radiation, and no discomfort.

'How is this study being paid for?'

This research is funded by a grant from the National Health and Medical Research Council (NHMRC: APP1036234).

'Are there risks to me in taking part in this study?'

There are few possible risks or discomforts associated with these procedures. In general, if at any time you feel uncomfortable for any reason, please inform the experimenter and more rest breaks can be given or the procedures can immediately be stopped. There may also be risks associated with this study that are presently unknown or unforeseeable.

'What happens if I suffer injury or complications as a result of the study?'

In the unlikely event that you suffer any injuries or complications as a result of this study, you should contact Dr St George as soon as possible on 03 6226 2887, who will assist you in arranging appropriate medical treatment.

'Will I benefit from the study?'

It is unlikely that you will benefit personally from participating in this research project, but the results will help our understanding of some basic functions of the healthy human brain. Indeed, we hope that the results of this study will eventually help us to treat impairments in balance associated with aging and neurological diseases.

'How will my confidentiality be protected?'

Your individual experimental data will be coded alpha-numerically and stored on a secure computer server that will be available only to the investigators via a password system. All future use of your data will be by the alpha-numeric code only to ensure anonymity. Your data will be retained securely at the University of Tasmania for at least five years. When it is no longer required by law, your data will be destroyed by the deletion of electronic files and shredding of documents.

You will be asked to sign an informed consent form to evidence your consent to participate in the study. Consent forms will be locked in a filing cabinet in the Cognitive and Motor Aging Laboratory at the University of Tasmania and kept separately from your data.

'What happens with the results?'

All data will be presented anonymously in any publications arising from this study. If you wish to be notified on the results of this study, please feel free to contact us.

'What should I do if I want to discuss this study further before I decide?'
If you have any queries, concerns or issues with this study at any time, please feel free to contact us:

Dr Rebecca St George (03 6226 2887 or Rebecca.StGeorge@utas.edu.au)

'Who should I contact if I have concerns about the conduct of this study?'
This study has been approved by the Tasmanian Health & Medical Human Research Ethics Committee. If you have concerns of complaints about the conduct of this study you should contact the Executive Officer of the HREC (Tasmania) Network on (03) 6226 6254 or email human.ethics@utas.edu.au. The Executive Officer is the person nominate to receive complaints from research participants. You will need to quote ethics reference number **H0014865**.

You will be provided with a copy of this information sheet and a statement of informed consent to keep. When finalized, results of the study will be posted on the University of Tasmania website, . It can be expected that results of individual studies will be available within a year of data collection.

Thank you for taking the time to consider this study.
If you wish to take part in it, please sign the attached consent form.
This information sheet is for you to keep.

Appendix D: Consent Form

UNIVERSITY of TASMANIA | FACULTY OF HEALTH

CONSENT FORM

Age-related changes in the cerebral cortex for human standing

(Version 3, September 25 2017)

Principle Investigators: Dr Rebecca St George, Dr Mark Hinder, Dr Michele Callisaya & Prof Jeff Summers

1. I have read the participant information sheet.
2. I have been informed of and understand the purposes of the study
3. I have been given an opportunity to ask questions
4. I understand I can withdraw at any time without prejudice
5. Any information which might potentially identify me will not be used in published material.
6. I agree to participate in the study as outlined to me.

Name of participant _____

Signature of participant _____ Date _____

I have explained this project and the implications of participation in it to this volunteer and I believe that the consent is informed and that he/she understands the implications of participation.

Name of investigator _____

Signature of investigator _____ Date _____

Appendix E: Medical Screener

Screening Questionnaire

Please read the following questions carefully and provide answers. The purpose of these questions is to make sure that there are no medical contraindications to your participation in the study. The information you provide will be treated as strictly confidential and will be held in secure conditions.

Exclusion criteria	
Do you suffer pain with standing or walking?	Y / N
Have you been diagnosed with a neuromuscular disorder? e.g. PD, MS	Y / N
Diagnosed Mental health disorder? (Schizophrenia)	Y / N
Have you ever had a brain injury? e.g. neurosurgery or a serious head injury/illness requiring hospitalisation?	Y / N
Neurological disorder? e.g. stroke, traumatic brain injury, dementia	Y / N
Do you have any metal in your head (outside the mouth) such as shrapnel, surgical clips, cochlear implants, or fragments from welding or metalwork?	Y / N
Is English your primary language?	Y / N
Criteria to note	
Do you have a heart condition?	Y / N
Are you taking or have you in the past taken any psychiatric or neuroactive medications? e.g. antidepressants, sedatives	Y / N
Are you pregnant or could you possibly be pregnant?	Y / N
Have you ever been told that your blood pressure is specifically high or low?	Y / N

Do you have diabetes?	Y / N
Do you have arthritis?	Y / N
Do you or have you ever suffered from dizziness?	Y / N

To ask in person	
In the last 12 hours, have you consumed more than 3 units of alcohol?	Y / N
In the last 12 hours, have you consumed any recreational drugs?	Y / N
In the last two hours, have you consumed more than 2 cups of coffee, or any other caffeinated drinks?	Y / N
Have you eaten today?	Y / N
Are you hydrated today?	Y / N
Do you get anxious of medical or clinical procedures?	Y / N
Have you had any falls in the last 6 months?	Y / N
If so, how many?	
A fall is defined as an unexpected event where you come to rest on the floor or ground	
Think of the last month and how many hours would you spend per week on average doing cardiovascular exercise?	
this is where your heart beats faster and you breathe faster than normal	
If you were to kick a ball, what would be your kicking foot?	
What is your height?	
What is your age?	

Appendix F: Analysis of Latency to Peak Amplitude

Time to peak amplitude was slower in the choice step (M = 7.59 s) compared to the simple step (M = 7.13 s) indicated by the main effect of step, F (1, 35) = 15.55, $p < .001$, $\eta p^2 = .31$. The main effect of secondary task, F (1.77, 62.11) = 63.82, $p < .001$, $\eta p^2 = .65$, $\varepsilon = .89$ and age F (1, 35) = 5.71, $p = .022$, $\eta p^2 = .14$ on latency to peak was significant. However, these were superseded by a significant Age x Task interaction, F (1.77, 62.11) = 8.59, $p = .001$, $\eta p^2 = .20$, $\varepsilon = .81$.

Contrast analysis revealed that when comparing the no added cognitive task condition to the FDR secondary task, although in both age groups latency to peak got slower, with the increased demands, time to peak neural activity was more slowed in young adults compared to older adults, F (1,35) = 8.23, $p = .007$, $r = .44$. Conversely, when comparing the FDR secondary task to the BDR secondary task, time to peak increased for both younger and older adults, and the effect was not more pronounced for any age group (not significant), F (1,35) = 3.04, $p = .090$, $r = .27$.

The Step x Age x Task interaction was not significant, F (1.62, 56.76) = .79, $p = .43$, $\varepsilon = .81$.